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AGRONOMIC ASSESSMENT OF SOLID MANURE INJECTION AND OPTIMIZATION OF THE ASSOCIATED MECHANICAL SYSTEMS

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Final Report

Research Report

Agronomic Assessment of Solid Manure Injection and Optimization of the Associated Mechanical Systems

Hubert Landry, P.Eng., Ph.D.
Project Leader

Hubert Landry

Philip Leduc, P.Eng., B.E.
Senior Manager
Research and Development

Philip Leduc

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1. Summary

PAMI has developed a device that can transport the product discharged from a manure land applicator and deposit it in a trench created by a coulter opener. This novel mode of manure land application has been dubbed injection in analogy with liquid manure injection. While sub-surface banded application best describes this land application technique, the more concise word injection is used throughout this report. Injection devices were implemented on a prototype precision manure land applicator developed at the University of Saskatchewan from 2001 to 2005. The enhanced prototype can perform surface and subsurface (injection) application of solid organic fertilizers.

The primary objective of the project reported herein was to conduct an agronomic assessment of the novel technology in comparison to the traditional practices of broadcast manure application and broadcast application followed by incorporation. The secondary objective of the project was to improve some of the mechanical systems that are used to perform solid manure injection.

Several key mechanical enhancements were brought to the prototype to improve its functionality. The improvements included an improved concept of flexible screw conveyor, a hydraulic stone removal system, and the modification and relocation of the coulters. The improved flexible conveyors are more robust and the stone removal system allows the equipment to run continuously even when foreign objects such as stones reach the injection units.

Manure was successfully applied to experimental plots in June 2007, May 2008, and May 2009. The crop yields over the three years of the study responded positively to cattle manure addition with the 2008 canola showing a stronger response than the oats in 2007 and 2009. Low availability of nitrogen (N) in cattle manure due to low content of available ammonium and slow mineralization of organic N contributed to lower yields of manure treatments compared to urea. The addition of manure increased grain and straw nitrogen (protein) and phosphorus contents. The highest yields and plant N concentrations were generally obtained when manure was combined with urea. In this case, the crop benefited both from high availability of N added as urea and also the other nutrients such as phosphorus and sulphur that the manure supplied. Nitrogen availability was increased as a result of repeated manure applications, especially at the high application rate. Combination of commercial N fertilizer with cattle manure is recommended in the initial years of cattle manure addition to compensate for low N availability and to help the crops utilize the excess phosphorus that is applied as manure. There was no evidence of excessive buildup of nitrate in the soil nor was there evidence of deep leaching below the surface layer. As expected, cattle manure addition tended to cause much greater increase in extractable soil inorganic phosphorus (P)

levels than extractable inorganic N levels. It was noted that the addition of urea along with manure helped to reduce the P accumulation in the soil. Cattle manure addition also increased the soil organic carbon content and had little influence on soil pH or salinity.

Especially in the first two years of the study, there was little difference between broadcast, broadcast and incorporated, and injection of the solid manure in terms of effects on crop yield. The lack of beneficial effect of in-soil placement of this manure source on crop yield may be explained by a very low content of inorganic N in the manure (ammonium) that would be susceptible to gaseous loss by volatilization and thereby benefit from in-soil placement. There was some evidence for slightly increased recovery of added N and P in manure when it was placed in the soil as injected or incorporated versus broadcast. In the last year of the study, 2009, there appears to be some additional benefit of the injection method of placement over the other two methods on yield, especially at the low rate of application. This was also observed in higher plant N concentrations and uptake of N in the oats grown in the third year of the study. This may be explained by the injection enhancing the decomposition of the manure to plant available inorganic forms deeper down in the soil profile (10 cm to 15 cm depth) that the roots can access better. Overall, for this manure source at this location, the agronomic benefits of in-soil placement of the solid manure on agronomic performance were relatively limited and may not justify the extra associated costs.

2. Objectives

The specific objectives of the project were:

Phase 1: Agronomic Assessment

1.1. To measure the agronomic performance of injected beef cattle manure.

1.2. To measure the agronomic performance of injected beef cattle manure with supplemental nitrogen.

1.3. To measure the agronomic performance of surface applied (uniformly broadcast) beef cattle manure.

1.4. To measure the agronomic performance of incorporated (surface applied followed by incorporation) beef cattle manure.

1.5. To compare the agronomic performance of the various land application strategies.

Phase 2: Mechanical Optimization

2.1. To study the effects of different bend patterns on the power requirements of the flexible conveyors.

2.2. To investigate different materials for the hoses that enclose the flexible conveyors.

2.3. To investigate means of reducing the diameter of the hoses that enclose the flexible conveyors.

2.4. To design and implement a system capable of minimizing the impact of foreign objects on the injection devices.

2.5. To quantify the effect of the moisture content of the product on the conveying force and to investigate means of adding water to the injection system for lubrication when applying dry products.

2.6. To develop a comprehensive strategy for future development of the prototype and technology transfer.

3. Project Description

Objectives 1.1 to 1.5 constitute the agronomic assessment program. Objectives 2.1, 2.2, and 2.4 were met in the first year (2007) of the project. The activities for year 2 of the project (2008) were limited to plot work. The final year of the project (2009) included field work and a theoretical investigation for objectives 2.3, 2.5, and 2.6 that will be presented in the results section of this report. The methodology used to meet the objectives of the mechanical optimization phase, when applicable, is best described along with the results.

The test site was located in Dixon, approximately 8 km west of PAMI's Humboldt station (legal location NW21-37-23-W2). The project is a joint effort by PAMI and by Dr. Jeff Schoenau and his team from the Department of Soil Science of the University of Saskatchewan who provided the agronomic expertise.

3.1 Field Experiments

The layout of the plots is presented in **Figure 1**. The soils at this location belong to the Cudworth Association and are a Black Chernozem formed in calcareous silty, lacustrune parent materials and have a loam surface texture (Saskatchewan Soil Survey 1989). The treatments were replicated in four blocks arranged in a north to south direction. The treatment list is as follows (the identifiers in square brackets are used in the report):

1. Check [C]
2. Disturbed check [DC]
3. Broadcast solid manure at 9 ton/ac (20.2 tonne/ha) [B 1X]
4. Broadcast solid manure at 18 ton/ac (40.4 tonne/ha) [B 2X]
5. Broadcast solid manure at 27 ton/ac (60.5 tonne/ha) [B 3X]
6. Broadcast and incorporated solid manure at 9 ton/ac (20.2 tonne/ha) [B&I 1X]
7. Broadcast and incorporated solid manure at 18 ton/ac (40.4 tonne/ha) [B&I 2X]
8. Broadcast and incorporated solid manure at 27 ton/ac (60.5 tonne/ha) [B&I 3X]
9. Injected solid manure at 9 ton/ac (20.2 tonne/ha) [INJ 1X]
10. Injected solid manure at 18 ton/ac (40.4 tonne/ha) [INJ 2X]
11. Injected solid manure at 27 ton/ac (60.5 tonne/ha) [INJ 3X]
12. Injected at 9 ton/ac (20.2 tonne/ha) with the addition of 70 lb/ac (78 kg/ha) banded urea N [INJ1X +U]
13. Injected at 18 ton/ac (40.4 tonne/ha) with the addition of 70 lb/ac (78 kg/ha) banded urea N [INJ2X +U]
14. Injected at 27 ton/ac (60.5 tonne/ha) with the addition of 70 lb/ac (78 kg/ha) banded urea N [INJ3X +U]
15. Banded urea N at 70 lb/ac (78 kg/ha) [Urea]

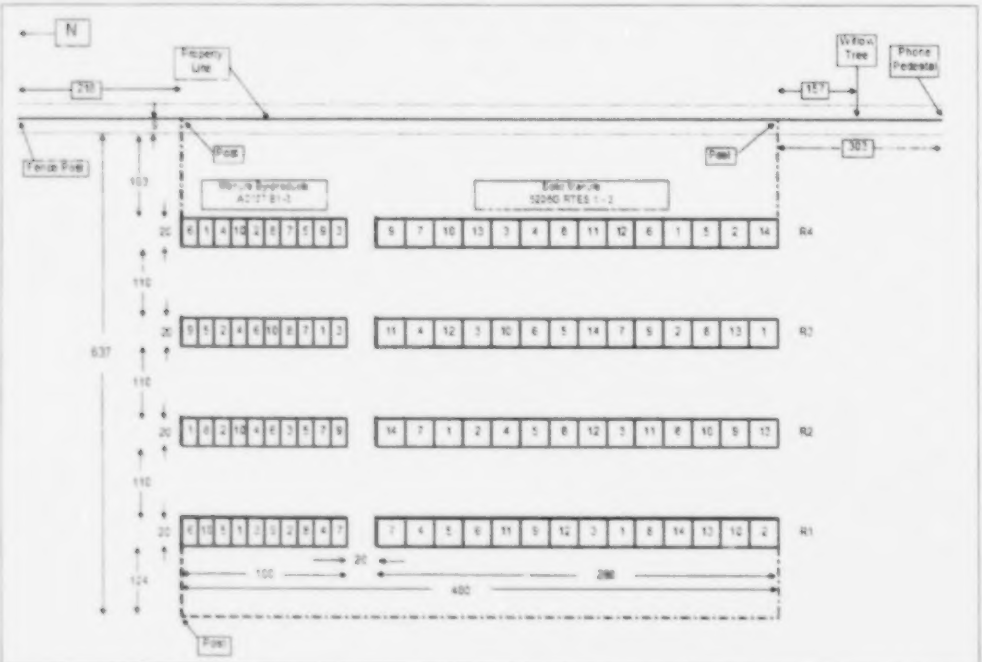

Figure 1. Plot Layout (the plots for the project reported herein are under PAMI Project Number 5206G; all dimensions are in feet; number in the plot indicate the treatment).

The broadcast treatments were achieved by applying the manure with PAMI's precision manure applicator (**Figure 2** and **Figure 3**). The broadcast and incorporated treatments consisted of applying the manure on the soil surface and then incorporating it using a disk. The injection was performed using PAMI's prototype applicator where manure was applied in six subsurface bands 12 in (30 cm) apart. Closer wheels 18 in. in diameter were used to cover the exposed injection trenches with soil. Commercial urea fertilizer (46-0-0) was banded into the soil using a small plot drill immediately after the injection of solid manure for those treatments requiring supplemental N.

Soil samples were collected from the site in the fall of 2007, 2008, and 2009 following harvesting operations. Soil samples were obtained from each plot in the study using a truck-mounted mechanical soil coring unit to 60 cm depth. Samples were analyzed for soil extractable nitrate-nitrogen (NO_3-N), ammonium-N (NH_4-N), phosphorus (P), and potassium (K). Basic soil properties such as pH, electrical conductivity (E.C.), and organic carbon (O.C.) were also measured.

Solid beef cattle manure samples were obtained by sampling ten random points of the feedlot stockpile. Samples were stored in 10 L plastic containers and placed into frozen storage (-20°C) prior to analysis of their constituent N and P nutrients. For the solid cattle

manure samples, individual containers were removed from frozen storage and thawed at room temperature for sampling for nutrient analysis. After thawing, samples were opened in the laboratory fume hood and stirred to mix the contents. Total N and P were measured by sulphuric acid peroxide digestion and soluble ammonium and phosphate by water extraction. Beef cattle manure that had been composting for one year was used in the first year of the study. That product was selected based on its availability and apparent homogeneity. A similar product was sourced in subsequent years.

Plant samples were collected from the plots just prior to the producer swathing the oat (2007), canola (2008) and oat (2009) crops. Duplicate 1 m^2 plant samples were cut from each trial plot. Plant samples were dried, weighed (total biomass weight was recorded), and threshed and cleaned (separated into grain and straw components). The grain and straw samples were digested to determine total nitrogen (N) and phosphorus (P).

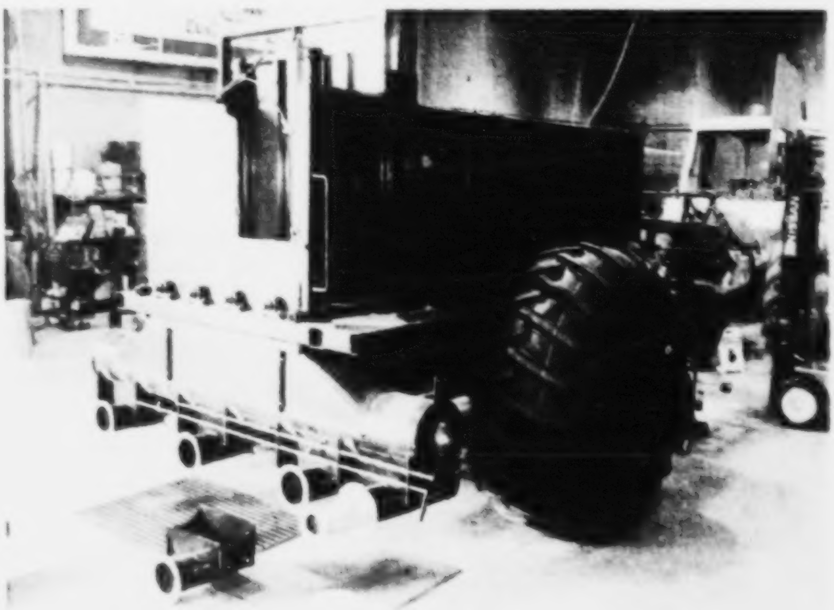

Figure 2. Precision Manure Land Applicator (injection units are being installed on the machine).

Figure 3. Precision Manure Applicator with Injection Toolbar.

4. Results and Discussion

4.1 Manure Analysis

The results of the analysis of manure samples are presented in **Table 1**.

Table 1. Composition of Manure Samples.

	Concentration (µg nutrient / g wet manure)				Total Solids
	Total P	Soluble NH_4	Soluble P	Total N	(%)
2007	2,439	16	120	4,304	34
2008	2,518	3	193	2,997	65
2009	3,560	3	205	9,350	73
Average	2,839	7	173	5,550	57

4.2 Crops Data

Oats were grown at the test site in 2007. There was a significant yield response of oats to the addition of solid beef cattle manure (**Figure 4** and **Figure 5**). The highest yields were measured at the high rate of application (3X; 27 ton/ac or 60.5 tonne/ha). Adding 70 lb/ac (78 kg/ha) of urea along with the manure gave the highest yield at the 1X (9 ton/ac or 20.2 tonne/ha) rate. Therefore, supplementation with urea to account for the low availability of nitrogen in solid cattle manure in the year of application is a good option if one desires to use a lower rate of manure application to avoid phosphorus loading.

Comparing broadcast application to broadcast application followed by incorporation reveals a significant difference in yield at the high rate of application with the broadcast treatment surprisingly having a higher yield. This may be related to the hot and dry conditions prevailing during the summer of 2007 where the mat of manure on the surface of the ground may have contributed to reducing the surface temperatures and helped reduce evaporation. The lack of a general benefit of incorporation is also likely related to the low ammonium content and low potential for volatilization losses of the nitrogen contained in the manure. For the same rate of application, the injected treatment was not significantly different in yield when compared to the broadcast and the broadcast followed by incorporation treatments.

In 2008, canola was grown at the test site. Compared to the unmanured, unfertilized control treatments, the addition of manure and urea increased total biomass and canola grain yield. There was no significant effect of rate of manure application on canola yield except for the 3X (27 ton/ac or 60.5 tonne/ha) injected rate that was of significantly higher yield than the 1X (9 ton/ac or 20.2 tonne/ha) injected rate. The greatest treatment effect was observed for the injection of solid manure with the addition of urea. The greater response of canola yield to treatments observed in 2008 as compared to oat

yield in 2007 can be explained by the greater nutrient requirement of canola compared to oats. The treatments including 70 lb/ac (78 kg/ha) of nitrogen as urea in addition to the cattle manure resulted in significantly higher canola yields than the other treatments, including urea alone. It is apparent that the benefit is partly from the urea providing additional plant-available nitrogen that the manure does not provide. It also seems that the injected manure is providing additional benefits when combined with urea, likely from the other nutrients it contains.

The mode of application of solid manure had no impact in 2008 with broadcast, broadcast and incorporated, and injected treatments producing similar yields at the same rate of application. As in 2007, the lack of a general benefit to incorporating or injecting manure is likely related to the low ammonium content and low potential for volatilization losses of the nitrogen contained in the manure.

Oats were seeded again in 2009 at the test site. As in previous years, a significant oat grain and straw yield response to manure addition treatments compared to the unmanured, unfertilized control treatments was measured again in 2009. Unlike 2007 and 2008, there was a rate effect in oat yield response in 2009 with 3X (27 ton/ac or 60.5 tonne/ha) manure treatments producing significantly higher yield than the low rate (1X). There was a response to the addition of urea at the 1X rate of manure but not at the 2X and 3X rates. Since 2009 represents the third consecutive year of manure application, it appears that sufficient mineralization of accumulated organic nitrogen in the soil has now taken place at the 2X and 3X rates to meet the crop nutrient requirements especially at the 3X rate of application. The 1X manure treatments continue to yield less than the urea treatments indicating that the supply of nitrogen from 9 ton/ac (20.2 tonne/ha) for three years is not yet sufficient to meet the crop nitrogen requirements.

For the effects of placement on oat grain yield, there was little difference between surface broadcast, and broadcast and incorporated treatments at the same rate of application. However, there was a trend for the injected manure to yield slightly higher than the broadcast and broadcast and incorporated treatments, especially at the low rate (1X) of manure application. In previous years (2007 and 2008), there was no apparent benefit to injection. A possible reason for the observed yield benefit in 2009 is that the in-soil injection has accelerated the decomposition and release of available nutrients through mineralization, also supported by the results of complementary experiments that showed increased soluble nutrient in the runoff water in this treatment. As the injection was found to reduce the concentration of nutrient at the surface (0 cm to 5 cm) and increase the concentration at depth (5 cm to 10 cm) compared to the other placement methods, the lower degree of stratification of nutrient in the injected treatment may also be favourable in reducing volatile losses of nitrogen to the atmosphere as ammonia as the manure undergoes decomposition.

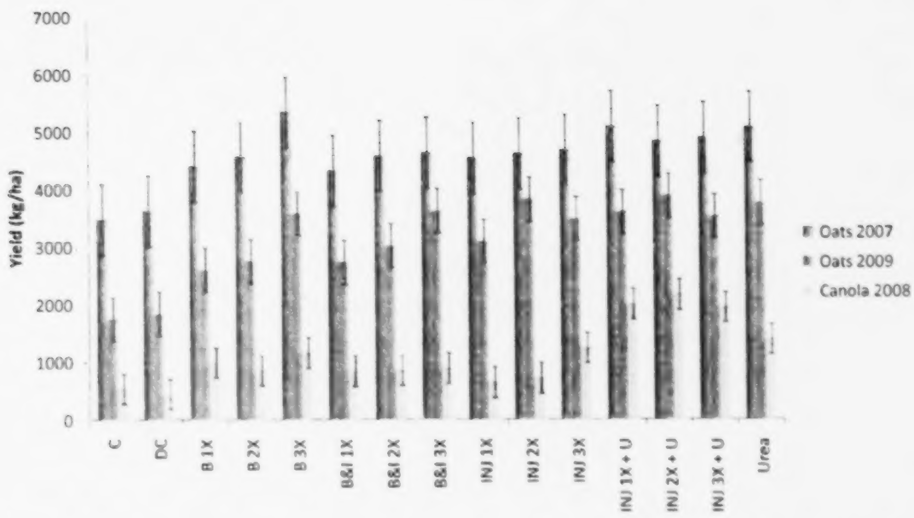

Figure 4. Grain Biomass for Fifteen Fertilization Treatments and Three Crop Years (the error bars represent the $LSD_{0.10}$ value for each series (year) of treatments).

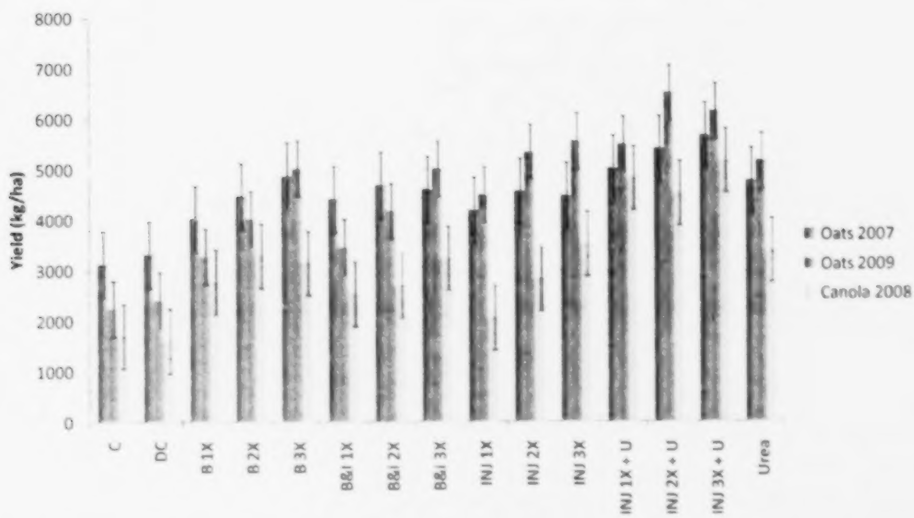

Figure 5. Straw Biomass for Fifteen Fertilization Treatments and Three Crop Years (the error bars represent the $LSD_{0.10}$ value for each series (year) of treatments).

In 2007, the concentration of nitrogen in the grain generally increased with increasing application rate of solid manure (**Figure 6**). Lower plant nitrogen concentrations for the broadcast treatment suggest some lower nitrogen recovery from solid manure when broadcasted than when incorporated or injected. The injected solid manure has grain and straw nitrogen concentrations that are similar or slightly above the broadcast and

incorporated treatments and higher than the broadcast treatment (**Figure 6** and **Figure** 8). A similar trend was noted for the phosphorus concentration in grain and straw (**Figure 7** and **Figure 9**) with highest P concentration in the grain in the injected treatment. Overall, there were not great differences in grain and straw nutrient concentrations between the broadcast and incorporated and the injected treatments. The highest grain and straw N concentrations were the treatments where urea was added along with the solid manure.

Canola grain nitrogen content was only slightly increased by manure application reflecting the relatively low availability of the nitrogen contained in the manure. Both grain and straw phosphorus concentrations were significantly increased indicating a significant contribution of manure phosphorus to plant-available P in the soil. At the 1X rate, grain and straw nitrogen concentration tended to be higher for broadcast and incorporated and injection treatments than broadcast only indicating greater nitrogen recovery from in-soil placement. This trend was also observed in 2007. This effect, however, was not observed at higher application rates. The injection treatments with additional urea produced the highest plant nitrogen concentrations.

As observed in the previous two years, grain and straw nitrogen concentrations were increased by the application of manure in 2009. The grain nitrogen concentrations in the injected treatment tended to be higher or similar to the broadcast and the broadcast and incorporated treatments following trends observed in 2007 and 2008. The higher plant nitrogen concentrations along with the higher yields noted for the injection, especially at the 1X rate, indicated that injection is providing some benefit in enhancing crop uptake and recovery of manure N possibly by reducing ammonia volatilization losses or more likely enhancing decomposition to available forms. The plant phosphorus concentrations were less affected by manure application than in 2008 likely due to the greater ability of oats to scavenge soil phosphorus when compared to canola.

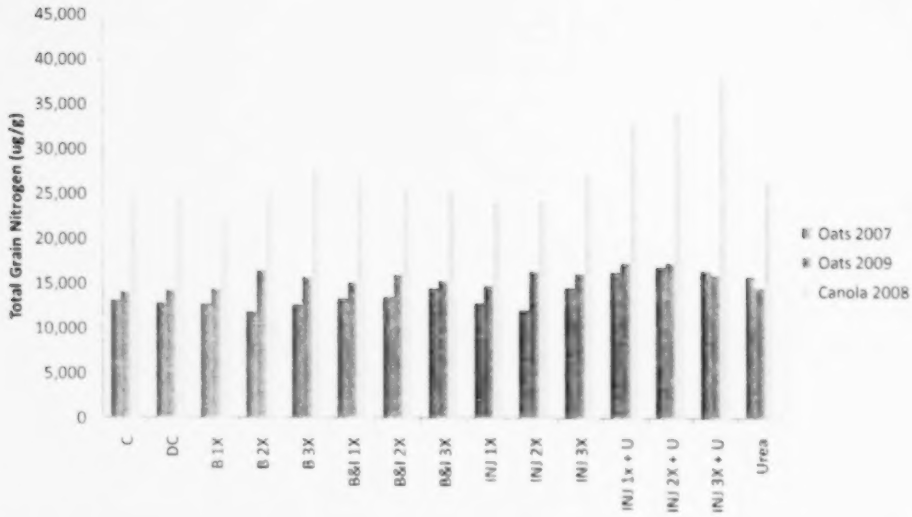

Figure 6. Grain Nitrogen Concentration for Fifteen Fertilization Treatments and Three Crop Years.

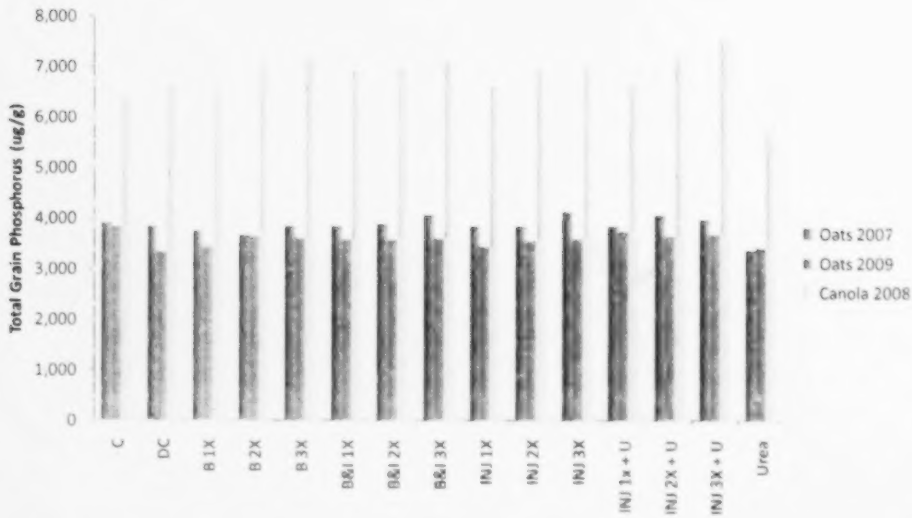

Figure 7. Grain Phosphorus Concentration for Fifteen Fertilization Treatments and Three Crop Years.

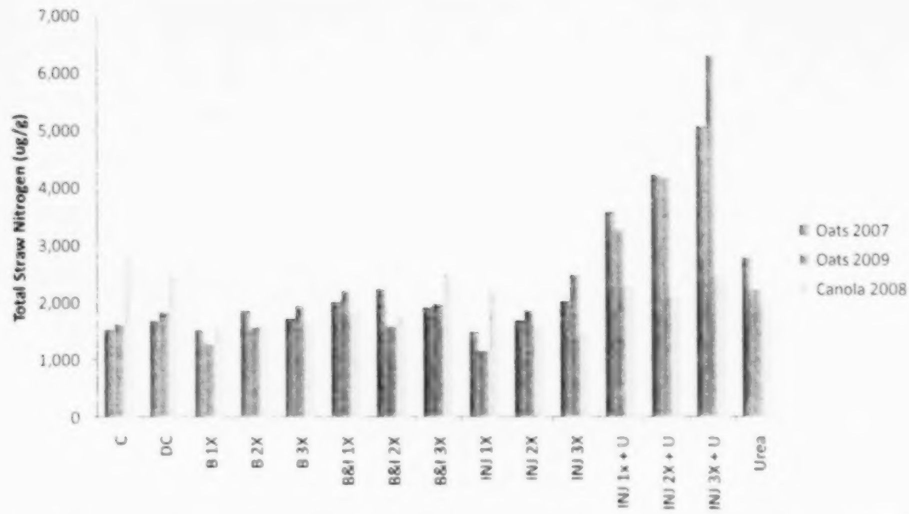

Figure 8. Straw Nitrogen Content for Fifteen Fertilization Treatments and Three Crop Years.

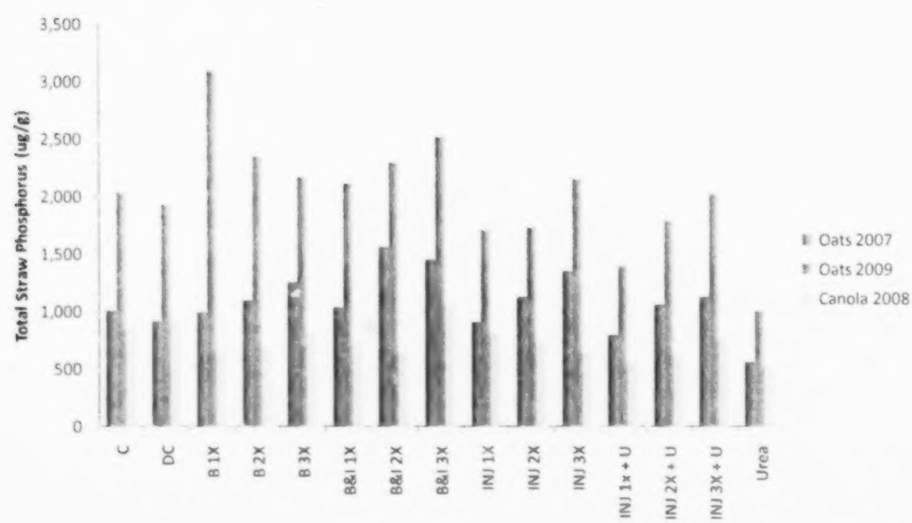

Figure 9. Straw Phosphorus Content for Fifteen Fertilization Treatments and Three Crop Years.

4.3 Soils Data

The addition of beef cattle manure caused some small but nonsignificant increases in electrical conductivity (salinity) (**Figure 10**). There was no significant effect of application method on the electrical conductivity. The soil pH was also not significantly affected by the treatments (**Figure 11**). The organic carbon concentration in the 0 cm to 15 cm depth increased with application rate for all modes of application (**Figure 12**). The organic carbon concentration increased by approximately 0.4% to 0.5% C from the control to the 3X rate of application. There was no significant effect of placement.

The soil test Modified Kelowna extractable phosphorus (0 cm to 15 cm) was significantly increased by the single manure application (**Figure 13**). The extractable P increased from approximately 14 kg/ha to greater than 60 kg/ha at the highest rates of application. This effect was not observed at greater depths. The large increase in soil P from a single application is consistent with the high phosphorus content of this manure. For the same rate of application, the broadcast and broadcast and incorporated treatments resulted in very similar phosphorus levels. Noteworthy is the high rate (3X) of injected manure producing significantly higher extractable phosphorus than the high rate of broadcast and broadcast and incorporated. This suggests that there may be better retention of phosphorus with injected manure when applying at high rates.

The residual soil nitrate in the fall of 2007 was generally low with not much difference between the manured treatments and the control. There was no significant rate effect and little difference in residual nitrate and ammonium content among application modes (**Figure 14** and **Figure 15**). Overall, the highest residual nitrate contents were measured for the high rate of injected manure with additional urea.

As in 2007, soil pH and salinity in 2008 were not significantly affected by the rate of application of manure or the mode of application. As well, similar to the previous year, the organic carbon concentration in the 0 cm to 15 cm depth increased with application rate for all modes of application and there was no significant effect of placement.

Manure application resulted in significant increases in extractable phosphorus again in the fall of 2008 (**Figure 13**). After two successive manure applications, the general trend for soil phosphorus concentration was to increase compared to the fall of 2007, with values of approximately 150 kg/ha present in the 3X treatments. There appeared to be no discernible effects of placement. Of the 3X treatments, the broadcast and the injected treatments had higher soil phosphorus than the broadcast and incorporated in the 0 cm to 15 cm depth. Adding urea to the injected manure reduced the soil phosphorus levels in the fall presumably due to greater yield and manure P utilization by the crop. Extractable potassium levels were also nearly doubled (**Figure 20**).

The soil nitrate levels in the fall of 2008 (**Figure 16**) tended to increase slightly with the application rate. As in 2007, soil nitrate levels were generally low with only the urea treatment showing slight elevation at depths of 30 cm to 60 cm. Placement had again little influence on soil nitrate and ammonium (**Figure 17**) in the 0 cm to 15 cm, 15 cm to 30 cm, and 30 cm to 60 cm depths with no discernable trend.

The repeated application of manure for three years at 20, 40, and 60 tonne/ha was associated with a trend towards slightly higher soil pH that was often not statistically significant. This is likely a result of the base cations such as calcium added in the manure. In 2009, some small increases in electrical conductivity were noted with manure

application reflecting the salts added with the manure. There was no evidence of any salinity buildup that would cause injury to any crop. As well, similar to the previous years, the organic carbon concentration in the 0 cm to 15 cm depth increased with application rate for all modes of application. There was no significant effect of placement method on pH, electrical conductivity, or organic carbon concentration in the 0 cm to 15 cm depth.

The soil nitrogen levels in 2009 in the 0 cm to 15 cm depth increased with manure application and generally increased with increasing rate of application (**Figure 18** and **Figure 19**). However, the amount of nitrate in the soil, even at the high rate, was still low (< 15 kg/ha). Also, there was no evidence of significant movement of nitrate below the 15 cm depth in the 15 cm to 30 cm and 30 cm to 60 cm layers except for a slight elevation at the high rates of injected manure with supplemental urea. The largest impact of manure addition observed in this study was on soil extractable phosphorus levels that were greatly increased by the addition of manure. The soil test phosphorus increased from 20 kg/ha in the 0 cm to 15 cm depth for the unfertilized control to over 200 kg/ha for the 3X (27 ton/ac or 60.5 tonne/ha) treatments. This is explained by the large amount of manure phosphorus, calculated to be approximately 500 kg/ha, added to the soil in this treatment over the three years of the study. These results again demonstrate that the accumulation of soil phosphorus can occur with the addition of beef cattle manure even over relatively short time periods when annual application rates are high. Manure placement appeared to have relatively little influence on extractable phosphorus in the 0 cm to 15 cm depth. There was some small elevation in extractable phosphorus in the 15 cm to 30 cm depth at high application rates, perhaps as leaching of organic phosphorus, consistent with results of other phosphorus leaching studies carried out at the University of Saskatchewan that showed some leaching of phosphorus out of the 0 cm to 15 cm intact soil cores collected from long-term cattle manure application trials.

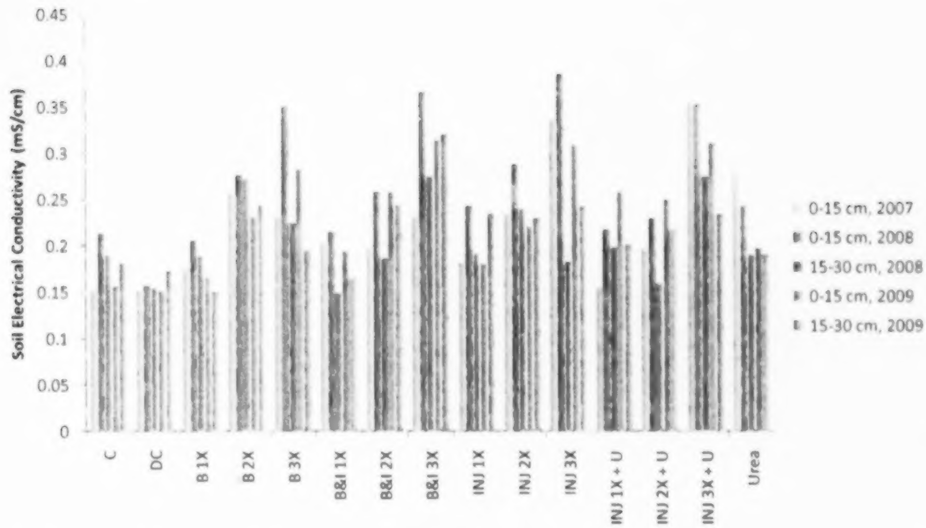

Figure 10. Soil Electrical Conductivity at Two Depths for Fifteen Fertilization Treatments and Three Crop Years.

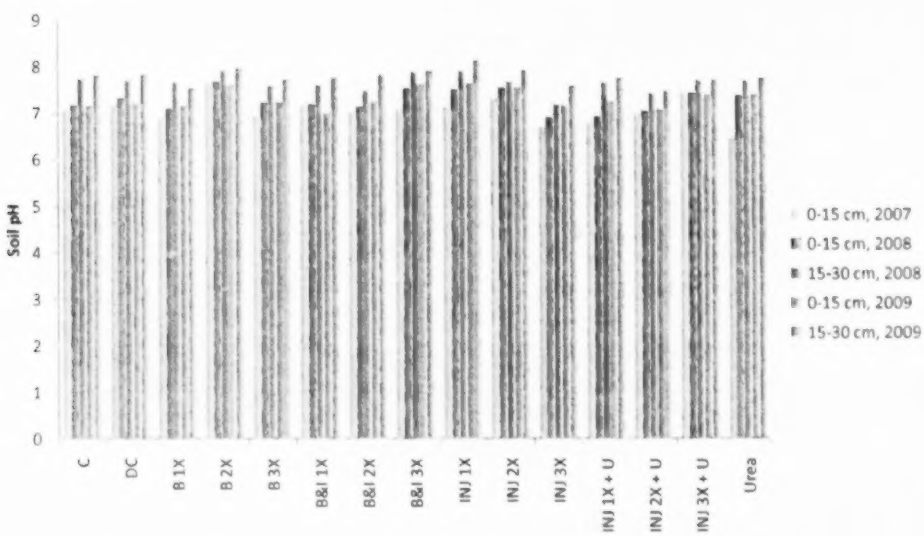

Figure 11. Soil pH at Two Depths for Fifteen Fertilization Treatments and Three Crop Years.

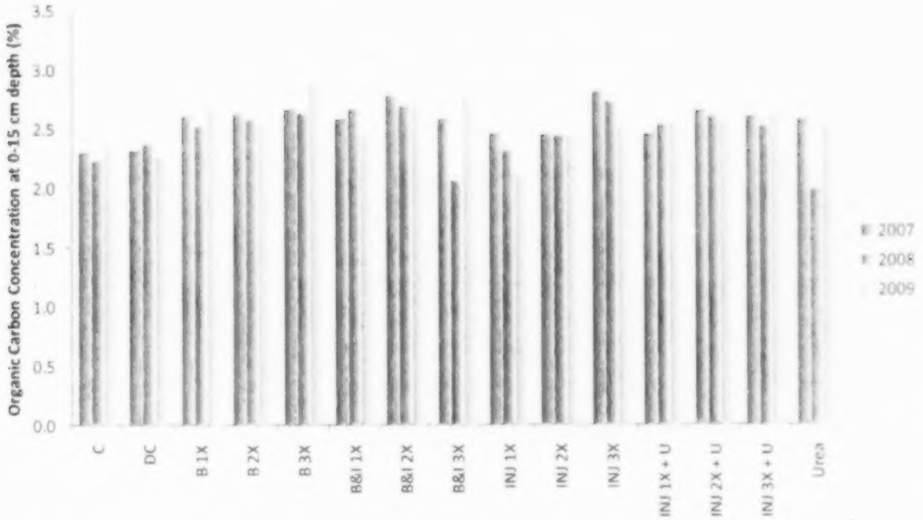

Figure 12. Soil Organic Carbon Concentration in the 0 cm to 15 cm Depth for Fifteen Fertilization Treatments and Three Crop Years.

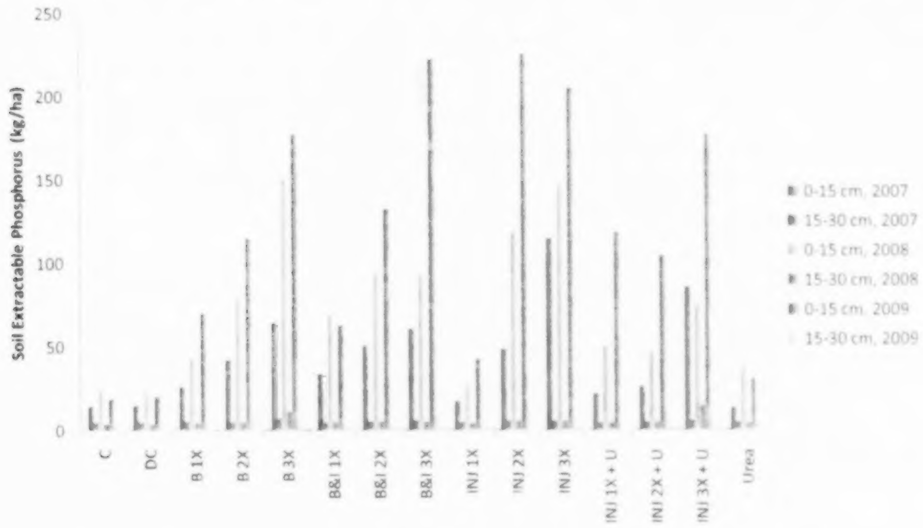

Figure 13. Soil Extractable Phosphorus at Two Depths for Fifteen Fertilization Treatments and Three Crop Years.

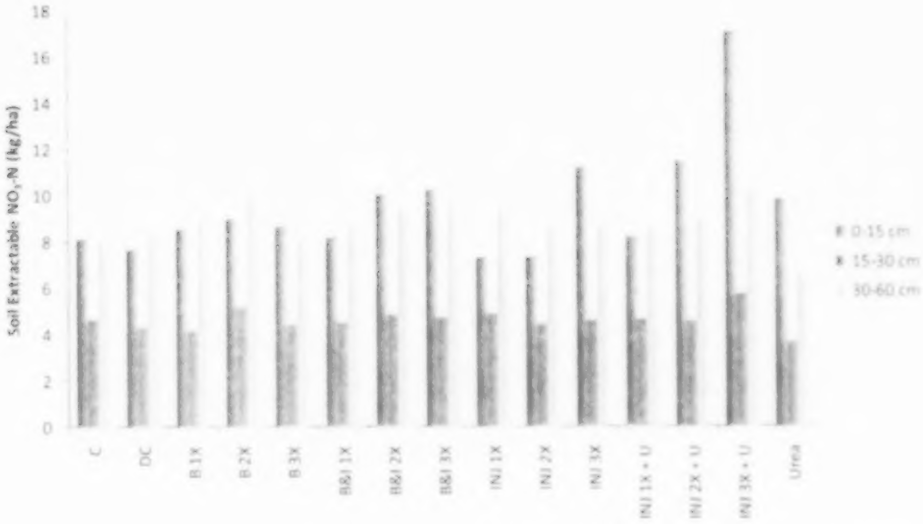

Figure 14. Soil Nitrate Content at Three Depths for Fifteen Fertilization Treatments in 2007.

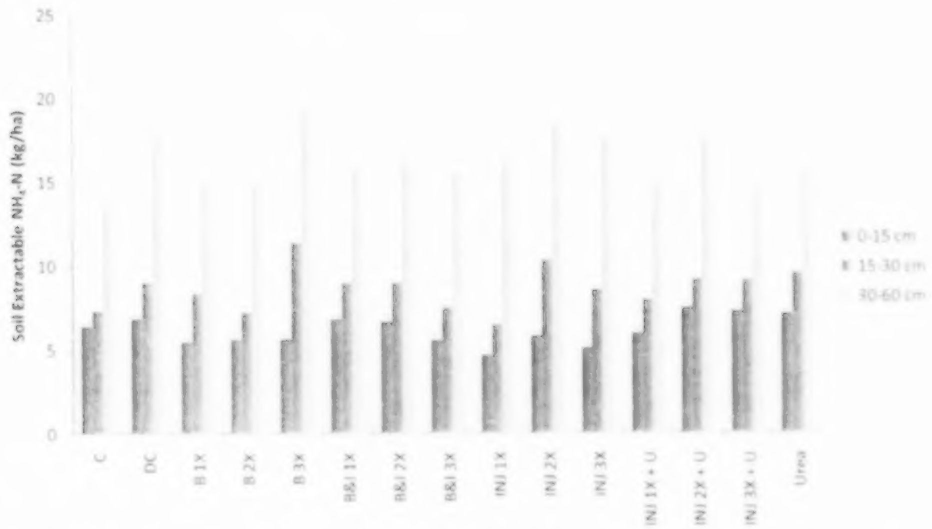

Figure 15. Soil Ammonium Content at Three Depths for Fifteen Fertilization Treatments in 2007.

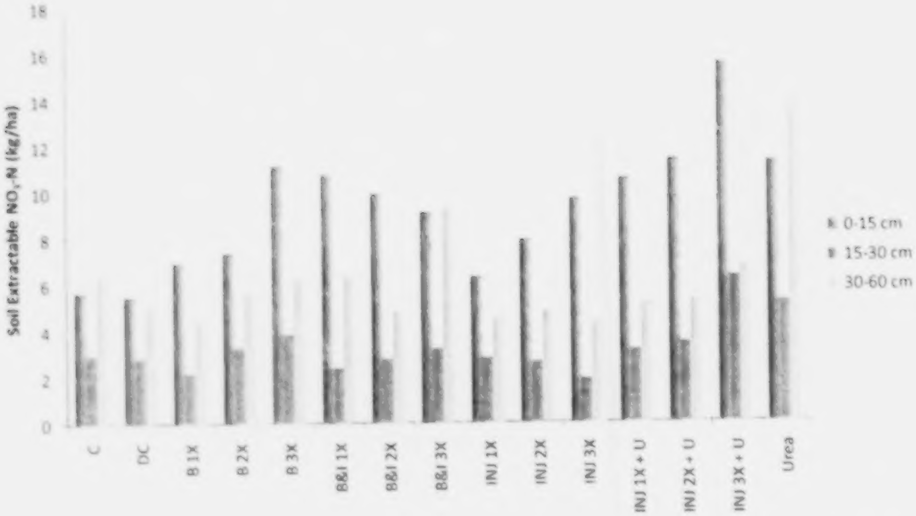

Figure 16. Soil Nitrate Content at Three Depths for Fifteen Fertilization Treatments in 2008.

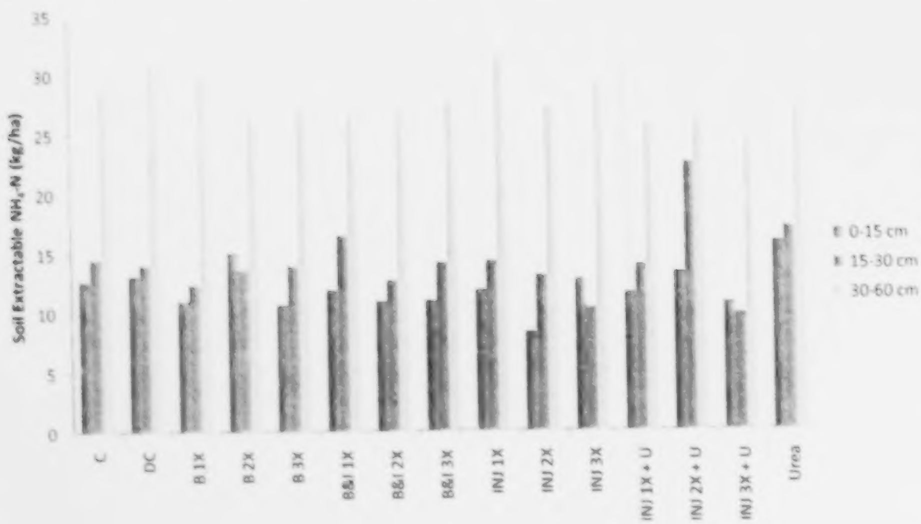

Figure 17. Soil Ammonium Content at Three Depths for Fifteen Fertilization Treatments in 2008.

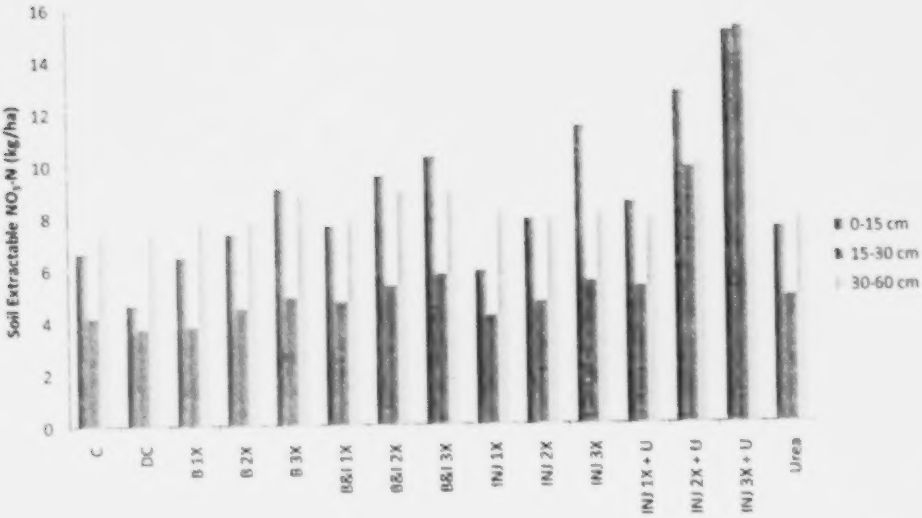

Figure 18. Soil Nitrate Content at Three Depths for Fifteen Fertilization Treatments in 2009.

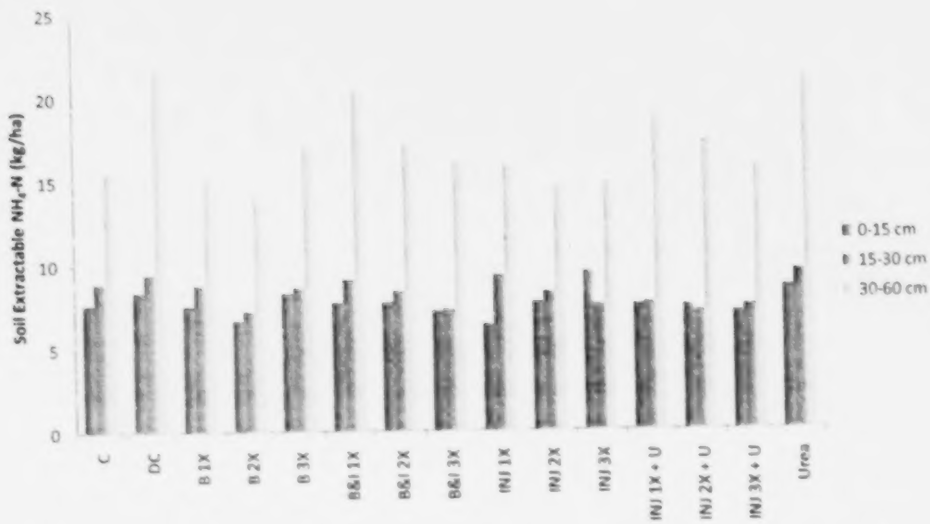

Figure 19. Soil Ammonium Content at Three Depths for Fifteen Fertilization Treatments in 2009.

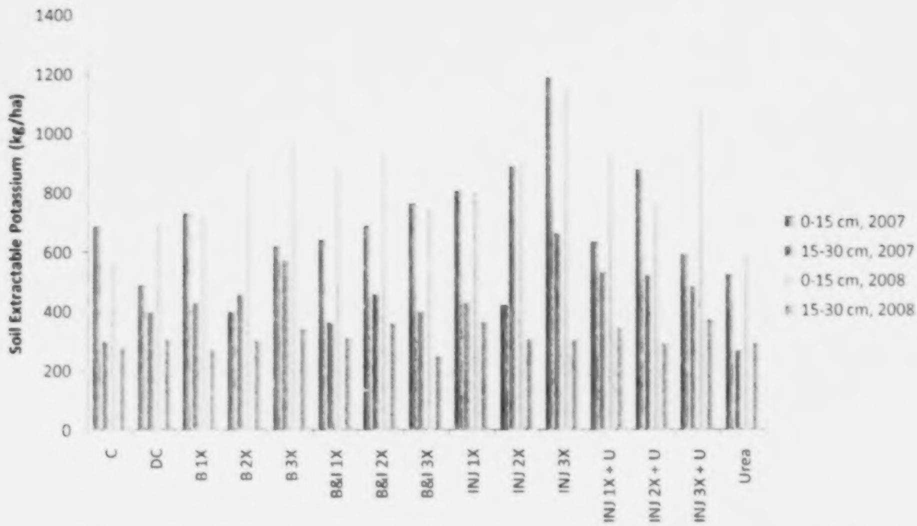

Figure 20. Soil Extractable Potassium at Two Depths for Fifteen Fertilization Treatments for 2007 and 2008.

4.4 Mechanical Optimization

The mechanical optimization phase was planned to take place concurrently with field activities and after the first and second year of field trials to take advantage of the lessons learned in the field. However, some key improvements were required at the project inception to ensure successful field trials. The two main components that were modified for this project were the flexible screw conveyors and the foreign object removal system.

4.4.1 Improved Flexible Screw Conveyors

The development of improved flexible screw conveyors encompasses specific objectives 2.1, 2.2, and 2.3. Shortcomings of the initial flexible conveyor concept (detailed in Progress Report ADF #20060147, October 25, 2007) prompted the development of an improved flexible screw conveyor concept to transport the material discharged by the transversal distribution conveyor of the precision manure applicator to the coulters that open the trenches in the soil. The resulting flexible conveyor features U-joints at strategic locations and a rigid steel tube core (**Figure 21**). The improved flexible conveyors successfully addressed the shortcomings that had been identified, namely the stretching and shortening of the steel cable used in the previous concept, general robustness and the ability to apply torque in both rotational directions.

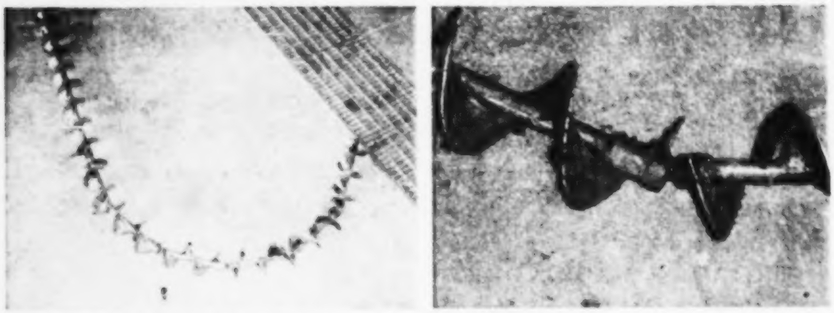

Figure 21. Flexible Screw Conveyor with Steel Tube Core and U-joint Articulations.

In attempting to optimize the flexible conveyors, the conveyor routing and hose materials were also investigated. The materials investigated were:

- PVC (plasticized poly-vinyl chloride) with rigid PVC helix
- High molecular weight PVC with rigid PVC helix
- EPDM (ethylene propylenediene-terpolymer) rubber with polyethylene helix
- Black rubber with spiralled textile cords
- Black rubber with heavy wire helix and synthetic textile cords
- Steel pipe and flexible galvanized exhaust tubing

The design criteria for the flexible tube/hose are:

1. Flexibility
2. Provides adequate structural support to the flexible screw conveyors
3. Low friction inside the tube/hose

The wire reinforced rubber hose is likely the most appropriate hose for the injection of solid manure. It is flexible enough to meet the requirements of the machine and provides good structural support. A fairly high friction force could however be observed with that hose. The wire reinforced rubber hose is also heavy at 6.6 kg/m. Despite its low rigidity, the flexible galvanized tubing is an interesting material with the lowest friction coefficient. Depending on future development of the prototype machine, flexible metal tubing may become sufficiently rigid or it could be reinforced so it becomes sufficiently rigid.

The bends imposed to a flexible conveyor will influence its power requirements. Running empty, a conveyor test bench allowed measuring power requirements for a flexible screw conveyor at 350 rpm. For configurations that include several gentle bends and with the conveyor straight, the measured power requirements were 1.9 kW and 1.7 kW, respectively. The same scenario with a rotational velocity of 500 rpm generated power requirements of 3.7 kW and 4.0 kW. When the conveyor was operated at 350 rpm with gentle bends and discharged 1.5 kg/s of manure, power requirements of 5.0 kW were measured. Several factors influence the power requirements of the flexible conveyors, namely their rotational velocity, number and radius of bends, hose material, type of

product conveyed, and moisture content of the product conveyed. The measured data provides baseline information, and the recommendation is to limit the number of bends and their radius. As for the product conveyed, it appears that a certain degree of lubrication is required. Sand-like, dry compost has been observed to flow well in a flexible conveyor. But, the discharge rate must be kept low as product accumulation inside the conveyor tube will create very high friction and blockages that can stall the system or damage the tube that encloses the conveyor.

4.4.2 Foreign Objects Removal System

Among the many technical challenges involved in the development of a solid manure injection technology, the requirement for a system that can handle the foreign objects that are inevitably present in manure is an important one. Because the injection of solid manure requires conveying a relatively large volume of product in a hose of limited diameter, foreign objects need to be taken out of the flow of product. The foreign objects removal system takes advantage of the hydraulic circuit that was already in place to power the six individual injectors. Based on observations that a large majority of obstructions occur in the conical part of the injector where the feeding screw conveyor is tapered down to match the diameter of the flexible screw conveyor (**Figure 22**), a spike in system pressure proved to be an appropriate triggering event for the controller of the foreign object removal system.

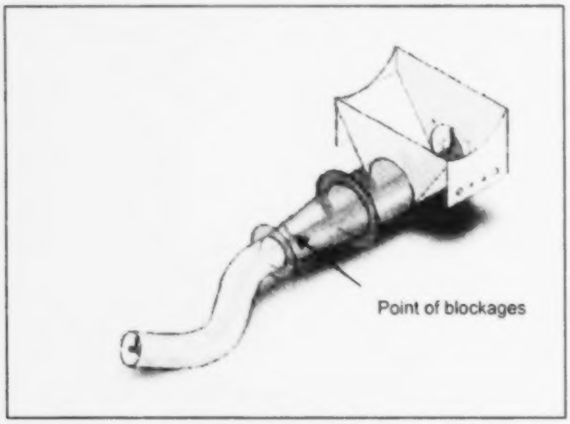

Figure 22. Part of the Injector that is Prone to Obstructions Caused by Foreign Objects.

The hydraulic circuit of each injector was modified to include a pressure transducer and a solenoid-operated selector valve. A programmable logic controller (PLC) is used to control the system. When a pressure spike is detected, the PLC sends an excitation signal to the selector valve to reverse the direction of rotation of the injector. When the programmable time delay has expired, the rotation of the conveyor is returned to its normal operating direction. The motor of each injector was relocated to open up an area for the product, with the foreign object, to flow out of the machine (**Figure 23**) when the

injection units are running in reverse. **Figure 24** presents a simplified hydraulic circuit diagram for two injection units.

Figure 23. The Motor Powering each Injector was Relocated to Allow the Product to Flow Out of the Machine when the Direction of Rotation of the Screw Conveyor is Reversed.

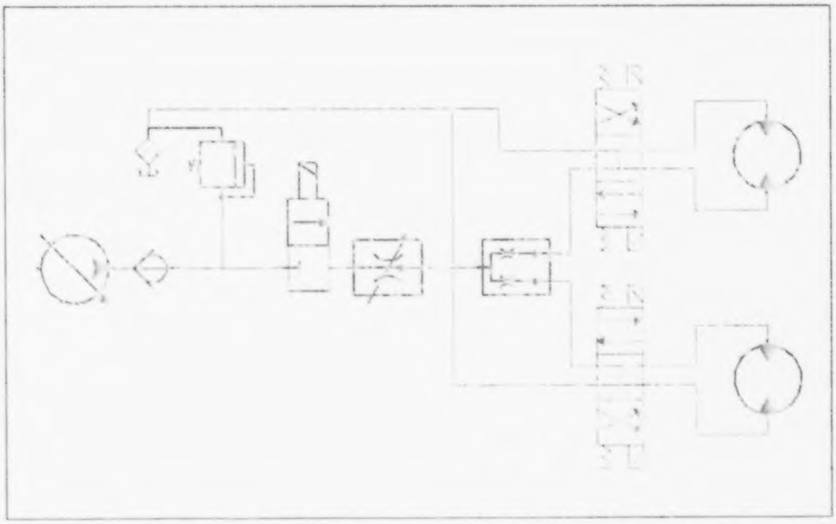

Figure 24. Simplified Hydraulic Circuit Diagram for Two Injection Units.

4.4.3 Diameter of the Flexible Conveyors

To minimize soil disturbance, the flexible conveyors should be as small as possible. It is PAMI's opinion that the smallest practical conveyor diameter has been used. Additional power would be required to convey the product in a smaller hose, and the risk of blockages at the tapered section of the injection units would be increased.

4.4.4 Effect of Moisture Content

The moisture content of the product has been observed to have an influence on how well it gets transported by the flexible conveyors. A very high moisture content (sludge-like product) was observed to provide good lubrication and easy flow. Experiments were carried out with a product that had a moisture content such that it would just form a pile. That product flowed well through the flexible conveyors with lubrication and gravity flow contributing. A very dry sand-like compost was also put through the machine. The compost was successfully moved by the flexible conveyors, but the flowrate had to be limited to avoid overfilling the flexible conveyors. The dry compost did not provide lubrication to facilitate the flow through the plastic hoses, and the high bulk density of the product increased the power requirements. Also, the quantity of compost flowing to the conical section of the injection units had to be limited as the product undergoes compaction in that section of the system.

No quantitative data could be generated for the properties of the product and their influence on the performance of the injection system. Because of the limited size of the test plots and the need to avoid stoppages when applying manure to the experimental plots, the use of compost was favoured. The compost was less heterogeneous and did not contain as many stones as fresher manure. It was therefore selected to provide more uniform experimental conditions. The range of product, including manure type, particle size distribution and moisture content, that the machine can handle is not well defined at the time of writing this report. Additional research is required to identify the optimal operating parameters for various types of fertilizers.

Should lubrication be identified as necessary to convey certain fertilizers, a system could be designed to inject water at selected locations of the flexible conveyors. The system could take the form of a ring with multiple injection points that would fit over the hoses that enclose the conveyors. Water could be added to the product at specified time intervals.

4.4.5 Future Development

The results presented in this report provide essential data to plan the further development of the technology required to, and the practice of, injecting solid manure. The technical challenges have been overcome, and a functional prototype machine has been developed. The agronomic results suggest that the benefits of solid manure injection likely does not justify the additional cost. Complementary research found

significant reduction in odours and some increase in the production of certain greenhouse gases.

Additional research is required before the injection of solid manure can be proven to be a beneficial practice from an agronomic and environmental point of view. The technology required for the injection of solid manure is well advanced and a next-generation prototype would focus mainly on increasing the capacity of the machine. It appears that injection may be beneficial for specific fertilizers. For example, poultry manure can benefit from the odour reductions associated with its injection. Poultry manure is in fact targeted by US researchers that have contacted PAMI to gather information. Also, one must consider nontraditional product like municipal waste sludge or compost. These products, if applied on municipal land, could require better controlled modes of application such as injection. PAMI was also recently involved in the development of a machine to subsurface apply compost pellets for oilfield remediation where it is believed that the addition of organic matter during subsoiling operations has the potential to reduce or eliminate the risk of recompaction. This is an example of a nontraditional application for the technology and knowledge developed under this project.

5. Conclusion

PAMI optimized selected systems necessary to the subsurface application of solid organic fertilizers and carried out an agronomic assessment of this novel practice. The main enhancements to the prototype machine included the new concept of flexible conveyors that provided a much more robust option as well as a system that can automatically remove foreign objects without interrupting the machine.

Especially in the first two years of the study, there was little difference between broadcast, broadcast and incorporated, and injection of the solid manure in terms of effects on crop yield. The lack of beneficial effect of in-soil placement of this manure source on crop yield may be explained by a very low content of inorganic N in the manure (ammonium) that would be susceptible to gaseous loss by volatilization and thereby benefit from in-soil placement. There was some evidence for slightly increased recovery of added N and P in manure when it was placed in the soil as injected or incorporated in comparison to broadcast. In the last year of the study, 2009, there appears to be some additional benefit of the injection method of placement over the other two methods on yield, especially at the low rate of application. This was also observed in higher plant N concentrations and uptake of N in the oats grown in the third year of the study. This may be explained by the injection enhancing the decomposition of the manure to plant available inorganic forms deeper down in the soil profile (10 cm to 15 cm depth) that the roots can access better. Overall, for this manure source at this location, the agronomic benefits of in-soil placement of the solid manure on agronomic performance were relatively limited and may not justify the extra associated costs.

Additional research is required to determine if other types of manure could benefit from subsurface application. Also, nontraditional markets should be considered for future development. The sub-surface application of compost pellets during subsoiling of oilfields for remediation purposes is a good example of such nontraditional markets. During the course of this project, PAMI has developed unique knowledge and has improved a field-scale prototype that can be used to conduct additional research.

One important issue that has been identified is the lack of data on the agronomic and environmental impacts of uneven solid manure application. The absence of such data does not allow for a proper assessment of the technology currently available and the need to develop precision manure application technology and improved modes of application such as subsurface application.

A manuscript for publication in Transactions of the ASABE is in preparation. Results of this project were also published in:

King, T., Schoenau, J.J., and Landry, H. (2009). Solid manure injection. Saskatchewan Ministry of Agriculture Research Update. December 15, 2009, Saskatoon, SK.

King T., Schoenau, J.J., and Landry, H. (2009). Agronomic and environmental performance of solid manure injection technology. Tri-Provincial Manure Management Conference Proceedings, October 21 - 22, Nisku, Alberta.

King T. and Schoenau, J.J. (2009). Impact of manure placement on nitrogen and phosphorus in runoff from a soil in east central Saskatchewan. Proceedings of the 2009 Soils and Crops Workshop, February 25-26, Saskatoon, Saskatchewan. (on CD).

King T., Schoenau, J.J., and Landry, H. (2008). Effect of solid cattle manure injection on nutrient recovery in a Black Chernozemic Saskatchewan soil. In Abstracts of the Canadian Society of Soil Science Annual Meetings. July 6 - 10, 2008, Prince George, British Columbia. p 111

King, T., Schoenau, J.J., and Landry, H. (2008). Effect of solid cattle manure injection on oat production in east central Saskatchewan. Proceedings of the 2008 Soils and Crops Workshop, February 28 - 29, Saskatoon, Saskatchewan. (on CD)

Schoenau, J.J. and King, T. Swine manure study. Melfort Research Farm Field Day, July 23, 2008, Melfort, SK (20 present)

6. Personnel

6.1 PAMI Manpower Supplied

It is PAMI's policy not to release individual salary information. The charge rates shown are the average salaries and benefits for each category of employee and are as shown in the ADF application. The benefit and overhead costs associated with salaries are partially to the PAMI applicant contribution and part of overhead is applied to other project costs.

6.2 Salaries – As of October 30, 2009

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7. Expense Statement

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